AP Biology

Lab: Energy Dynamics in an Ecosystem

BACKGROUND

Almost all life on this planet is powered, either directly or indirectly, by sunlight. Energy captured from sunlight drives the production of energy-rich organic compounds during the process of photosynthesis. These organic compounds are the **biomass** of the ecosystem. The biomass is equivalent to the **net primary productivity,** which is the net amount of energy captured and stored by the producers. This is also the amount of energy available to the next trophic level. The net primary productivity is derived from the **gross primary productivity**, which is a measure of the **total amount of light energy that was captured and converted into chemical energy *(organic compounds)*** during Photosynthesis. To obtain the **net productivity you must subtract all the energy that was used in cellular respiration and ultimately released as heat, from the gross productivity**.

In terrestrial systems, plants play the role of producers. Plants allocate that biomass (energy) to power their life processes or to store energy. Different plants have different strategies of energy allocation that reflect their role in various ecosystems. For example, annual weedy plants allocate a larger percentage of their biomass production to reproductive processes and seeds than do slower growing perennials. As plants, the producers are consumed or decomposed, and their stored chemical energy powers additional individuals, the consumers, or trophic levels of the biotic community. Biotic systems run on energy much as economic systems run on money. Energy is generally in limited supply in most communities. Energy dynamics in a biotic community is fundamental to understanding ecological interactions.

Learning Objectives

- To explain community/ecosystem energy dynamics, including energy transfer between the difference trophic levels.
- To calculate biomass, net primary productivity (NPP), secondary productivity, and respiration, using a model consisting of Brussels sprouts and butterfly larvae.

There are two parts to this lab:

Part 1. You will estimate the net primary productivity (NPP) of Wisconsin Fast Plants over several weeks

Part 2. You will calculate the flow of energy from plants (producers) to butterfly larvae (primary consumers). These calculations will include an estimate of (a) secondary productivity, which would be the amount of biomass added to the larvae and therefore available to the next trophic level, and (b) the amount of energy lost to cellular respiration.

PART 1: Estimating Net Primary Productivity (NPP) of Fast Plants

Primary productivity is a rate—energy captured by photosynthetic organisms in a given area per unit of time. Based on the second law of thermodynamics, when energy is converted from one form to another, some energy will be lost as heat. When light energy is converted to chemical energy in photosynthesis or transferred from one organism (a plant or producer) to its consumer (e.g., an herbivorous insect), some energy will be lost as heat during each transfer.

In terrestrial ecosystems, productivity (or energy capture) is generally estimated by the change in biomass of plants produced over a specific time period. Measuring biomass or changes in biomass is relatively straightforward: simply mass the organism(s) on an appropriate balance and record the mass over various time intervals. The complicating factor is that a large percentage of the mass of a living organism is water—not the energy-rich organic compounds of biomass. Therefore, to determine the biomass at a particular point in time accurately, you must dry the organism. Obviously, this creates a problem if you wish to take multiple measurements on the same living organism. Another issue is that different organic compounds store different amounts of energy; in proteins and carbohydrates it is about 4 kcal/g dry weight and in fats it is 9 kcal/g of dry weight).

Define the following terms, and then fill in the diagram below showing energy transfer in plants. Use the word "biomass" where necessary.

- **gross primary productivity -** ____
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- **net primary productivity -** ____
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- **secondary productivity -** ____
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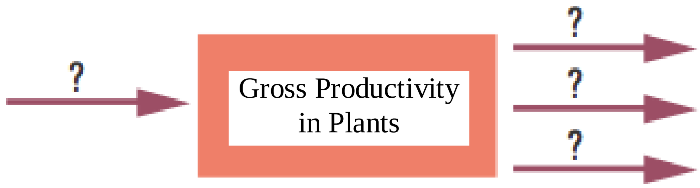
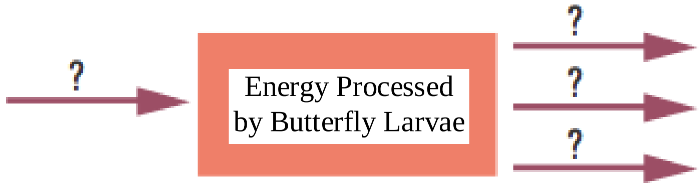
Review the energy transfer in plants by filling in the arrows below:

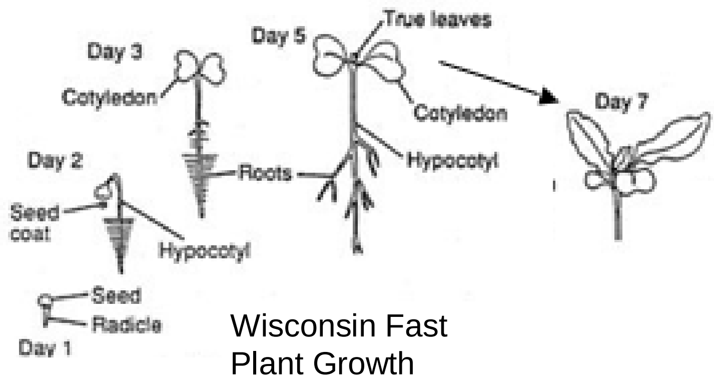


Review the energy transfer in primary consumers (butterflies) by filling in the arrows below:



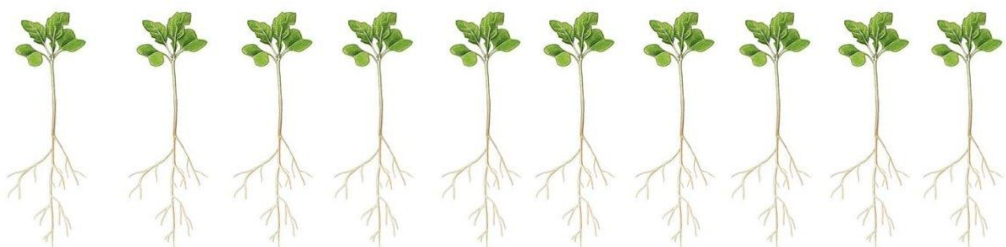
Procedure (For each section, you need to show ALL CALCULATIONS on the lines or spaces provided)

Step 1:
A student started 40 Wisconsin Fast Plants and grew them for 7 days under controlled conditions in a plant tray.



Wisconsin Fast Plant Growth

Step 2:
On **day 7**, she randomly selected 10 of the plants and removed them with their roots intact from the soil. She carefully washed the soil from the roots and then blotted the roots dry and measured the wet mass of the 10 plants collectively.



Wet Mass of 10 Plants (Day 7) = 19.6g

Step 3:
She then took the 10 plants and placed them in a ceramic drying bowl and placed them in a drying oven at 200°C for 24 hours. After 24 hours, she measured the mass of the dry plants.

Dry Mass 10 Plants (Day 7) = 4.2g

Step 4:
Use the following equation to calculate percent biomass:

$$\% \text{ biomass} = \frac{\text{mass of dry plants}}{\text{mass of wet plants}} \times 100$$

Calculate the percent biomass of the **10 plants**. ________________________________

Calculate the percent biomass **per plant**. ________________________________

Note how much of the plant's total mass is actually biomass (organic compounds), and how much is made up of water.

Calculations of Net Primary Productivity:

Each gram of a Fast Plant's **dry biomass** is equivalent to 4.35 kcal of **energy**. **Note: throughout this lab, the energy equivalents of biomass in kcal (plant or animal) were obtained in a laboratory using a calorimeter that measures the amount of energy per gram of organism.**

To calculate the amount of energy (in kcal) in the plants, multiply 4.35 kcal/g x the dried biomass (from previous page).

- Calculate the amount of energy (in kcal) in 10 plants that are 7 days old. ___________________

- Calculate the average amount of energy in 1 plant that is 7 days old. _______________________

Net Primary Productivity (NPP) is the amount of energy stored *(added)* as biomass **per day** by autotrophs in an ecosystem and is expressed in units of **kcal/day**.
In this section, you will be calculating the NPP per plant per day.

Organize your data from the previous page in the following table:

Age in days	Wet Mass/10 plants	Dry mass/10 plants	Percent biomass	Energy (g biomass x 4.35 kcal per 10 plants)	Energy (g biomass x 4.35 kcal per plant)	**Net primary productivity per day per plant**
7						

Note: To adjust the data to "per day," in the last column divide by 7 because the plants are 7 days old.

Step 5:
On **day 14**, she again randomly selected 10 plants and removed them with their roots intact from the soil. After cleaning the soil off the roots, she obtained the wet mass and dry mass of the plants.

Wet Mass 10 Plants (Day 14) = 38.4g
Dry Mass 10 Plants (Day 14) = 9.3g

Again, organize your data from the previous page in the following table:

Age in days	Wet Mass/10 plants	Dry mass/10 plants	Percent biomass	Energy (g biomass x 4.35 kcal per 10 plants)	Energy (g biomass x 4.35 kcal per plant)	**Net primary productivity per day per plant**
14						

Note: To adjust the data to "per day," in the last column divide by 14 because the plants are 14 days old.

Step 6:
On **day 21**, she again randomly selected 10 plants and removed them with their roots intact from the soil. After cleaning the soil off the roots, she obtained the wet mass and dry mass of the plants.

Wet Mass 10 Plants (Day 21) = 55.2g Dry Mass 10 Plants (Day 21) = 15.5g

Again, organize your data in the following table:

Age in days	Wet Mass/10 plants	Dry mass/10 plants	Percent biomass	Energy (g biomass x 4.35 kcal per 10 plants)	Energy (g biomass x 4.35 kcal per plant)	**Net primary productivity per day per plant**
21						

Note: To adjust the data to "per day," in the last column divide by 21 because the plants are 21 days old.

Summarize what you did to calculate the NPP of plants. Just use the example at 21days (3 weeks)

(Note: Even though you calculated % biomass to show you how much of the original plant mass was actually organic material you didn't need this value to calculate the NPP. However, in PART 2 of the lab you will need to calculate and use % biomass .

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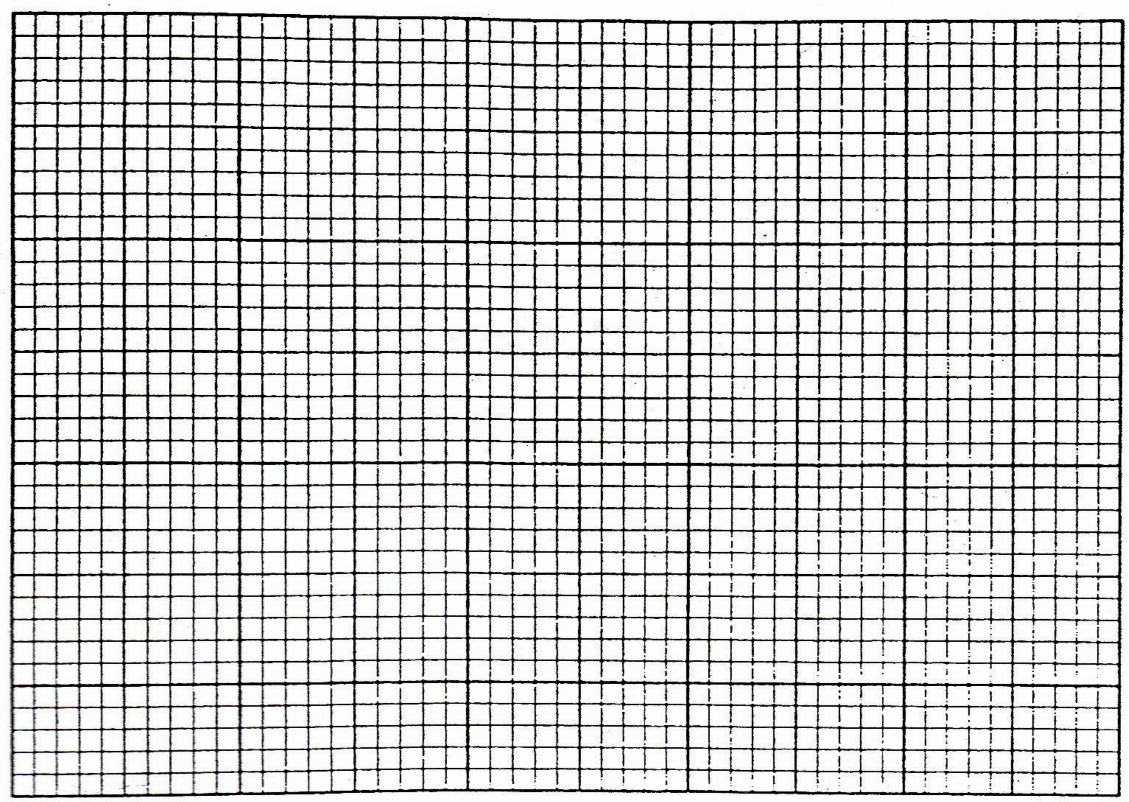
Step 7:
The NPP data for a sample class with 7 groups is shown in the table below. The data for Group 1 has been left out. **You are to fill in your data as Group 1**.

Class Data: Net Primary Productivity – Wisconsin Fast Plants

Time (Days)	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	**Average Data (Mean)**
7		0.25	0.25	0.27	0.26	0.27	0.26	
14		0.28	0.29	0.30	0.29	0.30	0.28	
21		0.31	0.32	0.31	0.32	0.33	0.32	



Step 8:

Data Analysis

- Graph the Class Average (mean) NPP vs. Time.
- Why does the NPP increase over time (as the plants grow and mature)?

PART 2: Estimating Energy Transfer from Producers to Primary Consumers

In this experiment, you will be using a simple two-step food chain using Brussels sprouts as the producers, and cabbage butterflies as the primary consumers.

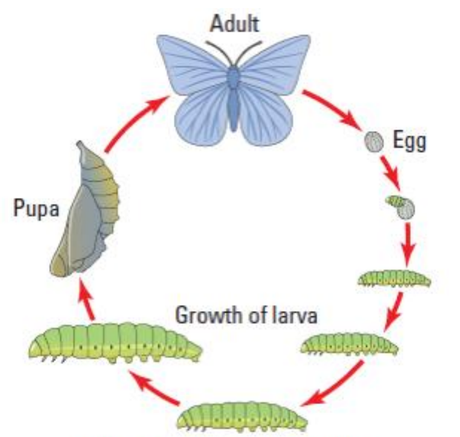
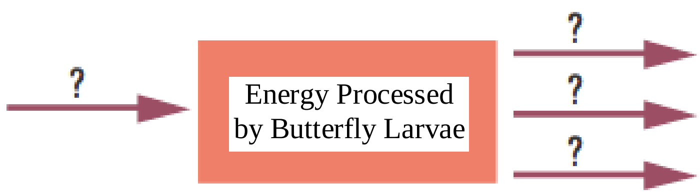


Figure 1. Butterfly Life Cycle

Review the energy transfer in primary consumers (butterflies) by filling in the arrows below:



In this part of the lab you will be using Brussels sprouts as your producers, and cabbage butterfly larvae as your primary consumers**. Refer to the diagram above, and on a separate piece of paper discuss with your group how you would go about calculating the secondary productivity (in kcal) and the amount of energy (in kcal) lost to cellular respiration.**

In order to calculate plant, larvae, and frass energy in kilocalories (kcal), you must multiply by known values measured in kilocalories for these organisms.
Example: to calculate plant energy, you multiple the biomass by 4.35 kcal/g, for the larvae you multiple biomass by 5.5 kcal/g, and for the frass you multiply by 4.75 kcal/g.

Explain why these values differ depending on which organism (or waste material) you are measuring?

Step 1:
The student took Brussels sprouts, which are in the same family (Brassicacae) as Wisconsin Fast Plants and placed them in an aerated container with air holes along with 10 caterpillar larvae that were 12 days old. (Figure 4)

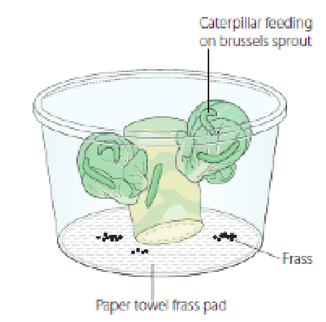


Figure 4. Brassica Barn

Before assembling the container, the wet mass of the Brussels sprouts and wet mass of the caterpillars was taken.

Wet Mass Brussels sprouts = 30g Wet Mass of 10 Larvae = 0.3g

Step 2:
After 3 days, she disassembled the container and took the mass of the components indicated below. At this point the caterpillar larvae were 15 days old.

Wet Mass Brussels sprouts = 11g Wet Mass 10 Larvae = 1.8g

Step 3:
She then used a drying oven to obtain the dry biomass of the 10 caterpillar larvae, the remaining Brussels sprouts, and the dried frass.

Dry Mass Brussels sprouts = 2.2g Dry Mass 10 Caterpillar Larvae = 0.27g Mass of Frass (Dry Egested Waste) from 10 Larvae = 0.5g

In order to calculate the flow of energy from plants to butterfly larvae, you will fist need to calculate the % biomass of both the plant and the larva. Use the information on this page to complete the following chart. You will than use the % biomass value to calculate energy flow.

	Brussel Sprouts	**10 Larvae**	**Frass**
Day 1 WET wt.			**N/A**
Day 3 WET wt.			**N/A**
Day 3 DRY wt.			
% Biomass Dry/Wet			**N/A**

Tables of Energy/Biomass Flow from Plants to Butterfly Larvae

You will be using the percent biomass of both plants and larvae to calculate the energy lost by plants or gained larvae in the following calculations. In part 1 of the lab the dried biomass was used to calculate net primary productivity. In part 2 of the lab you are using percent biomass because you cannot directly calculate the biomass for the Brussels sprouts or larvae on day 1.
Why? Answer on pg. 10

Table 1: Brussels Sprouts

	Day 1	**Day 3**	
Wet mass of Brussels Sprouts			gms consumed ___________
Plant percent biomass (dry/wet)			
Plant energy (wet mass x percent biomass x 4.35 kcal)			kcals consumed per 10 larvae ___________
Plant energy consumed per larvae (plant energy/10)			kcals consumed per larvae (÷ 10) ___________

Table 2: Butterfly Larvae

	Day 1	**Day 3**	
Wet mass of 10 larvae			gms gained ___________
Wet mass per individual			gms gained per larvae ___________
Larvae percent biomass (dry/wet)			
Energy production per individual (individual wet mass x percent biomass x 5.5 kcal/g			kcals gained per larvae ___________

Table 3: Frass

	Day 3
Dry mass of the frass from 10 larvae	
Frass energy (waste) = frass mass x 4.75 kcal/g	
Dry mass of the frass from 1 larva	

Table 4: Respiration

Respiration (show calculation)	**Day 3**

In part 1 of the lab the dried biomass was used to calculate net primary productivity. In part 2 of the lab you are using percent biomass because you cannot directly calculate the biomass for the Brussels sprouts or larvae on day 1. Why?

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Refer to Table 4 on the previous page to answer the next 2 questions.

What percent of the energy consumed by the larvae became biomass that is now available to the next trophic level? Show calculation.

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What percent of the energy consumed by the larvae was used in cellular rerpiration and eventually lost as heat? Show calculation.

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Are these values close enough to what you would expect given your knowledge of energy transfer in ecosystems ? Explain your answer.

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